ADDITIVE MANUFACTURING FOR COMPOSITE TOOLING

TIM SCHNIEPP
WE ARE

THE 3D PRINTING SOLUTIONS COMPANY
Our Solutions

» Investments in advanced applications spark innovation in targeted industries

» Custom solutions, such as certified materials, are developed to fit unique needs of each industry

» Dedicated personnel have deep expertise in education, dental, medical, aerospace, automotive and manufacturing
The Stratasys Ecosystem

1. 3D printers and production 3D printers
2. Stratasys Direct Manufacturing
3. Industry expertise and specialized applications
4. Stratasys Strategic Consulting
5. Professional Services and Customer Support
6. Extensive range of materials
7. Design and engineering communities
8. Strategic partnerships

Our customers
Today’s Event

Host

Kim Killoran
Marketing Project Manager
Stratasys

Presenter

Tim Schniepp
Business Development Director – Composite Tooling
Stratasys
WHAT IS FDM?
Stratasys Core Additive Manufacturing Technologies

**Fused Deposition Modeling**
Thermoplastic filament is heated to a semi-liquid state and extruded across computer-controlled tool paths to build parts layer-upon-layer.

**Material Jetting**
Deposits droplets of UV-cured resins in multiple colors and textures for fine-detailed prototypes.
FDM TOOLING
Tooling Applications

Assembly and Automation

Metal Forming

Thermoforming
Tooling Applications for Composites

Composite Lay-Up Tools

Coordinated Tool Family

Sacrificial (Wash-Out) Lay-Up Tools
Composite Tooling

FDM Composite Fabrication Applications

- Patterns
- Lay-Up & Repair Tools
- Consumable Tools / Cores
- Jigs & Fixtures

Masters
Pre Lay-up
Consolidation Tools
Low Temp
High Temp
Bond Fixtures
Intensifiers
Caul Plates
Sacrificial Tooling
Printed Cores
Integrated Interfaces
Trim Tool
Drill Tool
Check Fixture
Composite Tooling – Presentation Focus

FDM Composite Fabrication Applications

Patterns

Lay-Up & Repair Tools

Consumable Tools / Cores

Jigs & Fixtures

Masters

Pre Lay-up

Consolidation Tools

Low Temp

High Temp

Bond Fixtures

Intensifiers

Caul Plates

Sacrificial Tooling

Printed Cores

Integrated Interfaces

Trim Tool

Drill Tool

Check Fixture
Benefits of FDM Composite Tooling
Composite Tooling Today

Metal Tooling - ~75% of market

Model

Mold
$300-600K
6-12 months

Machining Fixture
$100-200K
3-4 months

Part Fabrication

FRP Tooling - ~25% of market

Model

Master
$40-60K
7-8 weeks

Hand Lay-Up + Machining

Mold
$40-60K
9-11 weeks

Machining Fixture
$40-60K
9-11 weeks

Part Fabrication

Current Pain Points

• High costs and long lead times
• High levels of touch labor
• Lead time paces entire development programs, prevents introduction of new technology, evolution, optimization, etc.
• Costly design changes
• Large, heavy tools – difficult to move and store

Benefits of FDM

• Disruptive time & cost savings
• Reduced lead times enable iteration, change, optimization
• Respond quickly to demand fluctuation
• Tailor the tool to the application vs. one-size-fits-all
• High temperature capable materials
• Handle tools with people, not cranes and forklifts
FDM Composite Tooling
FDM Composite Tooling Overview

Capable, cost effective lay-up tooling in days, not months

High temp, autoclave-cure compatible

- >350°F, 100+ psig

Eliminates the need for masters, machining, and assembly

Iterate, change and modify designs with relative ease

Key Considerations

- Cure temperature
- Tolerances, features
- Build orientation
- CTE impacts
- Surface prep/sealing
- Vacuum bagging, process details
FDM Sacrificial Tooling Overview

Easy-to-produce, cost-effective wash-out tooling for complex, trapped geometries

- Wash-out solutions capable up to 250 °F
- Break-away solutions capable of >350 °F

Eliminates complexity of traditional trapped tooling methods

- No casting, molding, machining…no mess
- No material phase changes (e.g., eutectic salts)
- No complex, multi-piece, collapsible tools or inflatable bladders
- No steep learning curves or extensive prior expertise required

Tools available in hours, not weeks or months

Iterate, change and modify designs with relative ease
Key Development Partners

Industry Collaborators

• Novel application development
• Complex geometry evaluation
• Technical input and knowledge sharing
• Testing and characterization

Many other significant contributors not listed per non-disclosure agreements
Composite Tooling

Key Considerations

- Cure temperature (and pressure)
- Coefficient of thermal expansion
- Accuracy / tolerances, design features
- Build orientation / design for additive manufacturing (AM)
- Vacuum bagging, structural integrity
- Surface preparation (tool sealing)
Temperature Capabilities

- ULTEM™ 1010 resin – highest temperature capability and lowest CTE
- ST-130™ sacrificial tooling – wash-out material for complex / trapped tooling

ULTEM is a registered trademark of SABIC or its affiliates or subsidiaries.
Coefficient of Thermal Expansion

- Best Practice – account for CTE in the tool design
- Use the relatively high CTE as an advantage
  Ex. increased compaction for a male mandrel with easier tool removal

<table>
<thead>
<tr>
<th>FDM Materials</th>
<th>μm/(m·C°)</th>
<th>μin/(in·F°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST-130 (soluble)</td>
<td>71</td>
<td>39</td>
</tr>
<tr>
<td>PC</td>
<td>79</td>
<td>45</td>
</tr>
<tr>
<td>ULTEM 9085</td>
<td>65</td>
<td>37</td>
</tr>
<tr>
<td><strong>ULTEM 1010</strong></td>
<td><strong>47</strong></td>
<td><strong>26</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conventional Tooling Materials</th>
<th>μm/(m·C°)</th>
<th>μin/(in·F°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tooling Boards</td>
<td>36 - 72</td>
<td>20 - 40</td>
</tr>
<tr>
<td>AL 6061 alloy</td>
<td>25</td>
<td>14</td>
</tr>
<tr>
<td>Tool Steel</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Invar</td>
<td>1.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Approximately 2X the CTE of aluminum tooling
Design and Build Considerations

Tolerances
- Fortus 900mc™: ± 0.035 inch or 0.0015 inch/inch

Build orientation impacts
- Surface finish, mechanical properties, build time

Build style impacts
- Material usage, build time, mechanical properties

Design for AM (DFAM)
- Design for cost and function
- Tailor the tool design to the application
Vacuum Bagging and Structural Integrity

Envelop bag when possible

Surface bagging also effective with sealed tools

Tool Construction impacts bagging approach
  • “Shell” style tools
    • Works well for both, easily handles 100+ psig
  • “Sparse” style tools
    • Envelope bagging – must be sized appropriately
    • Surface bagging eliminates crushing concerns (pressure evenly distributed on all sides)
Vacuum Bagging and Build Construction

Sparse Style Tool Construction

- Tailor raster spacing based on the application
- “Sparse” style tools
  - Surface bagging
    - Pressure distributes evenly
    - Sparse fill spacing impacts overall tool rigidity
    - Use uncapped (open) ends for venting and improved air flow
  - Envelope bagging – general guidelines per the table below:

<table>
<thead>
<tr>
<th>Consolidation Pressure</th>
<th>Max. Sparse Spacing</th>
<th>~Relative Material Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum only – 40 psi</td>
<td>0.5 inch</td>
<td>1.0</td>
</tr>
<tr>
<td>≤ 60 psi</td>
<td>0.25 inch</td>
<td>1.3</td>
</tr>
<tr>
<td>80 – 100 psi</td>
<td>0.1 inch</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Note – Sparse spacing is based on a wall thickness of 0.1 inch (thickness has minimal impact on pressure capability).
Tool Sealing and Preparation

FDM Characteristics

- Inherently porous structure
- Perceptible build layers
- As-built surface roughness – 200+ μin. Ra

Addressed Through Tool Sealing

- Manual abrasion, sealer application, final polish → resulting roughness < 16 μin. Ra
- Epoxy paste and film adhesive sealers
  - BJB TC-1614
  - Hysol EA-9394
  - 3M AF-555, AF-163
- Adhesive-backed FEP films
  - Airtech Tooltec CS5
  - Airtech Toolwright 5
Customer Stories
Customer Success Story – Lay-Up Mandrels

Enabling innovation for a leading business-jet OEM

- High-temperature, cost-effective lay-up tooling for an innovative “single shot” composite aileron (patent pending)
- Guided material selection (ULTEM 1010 resin) and optimization of the design and build parameters
- Leveraged experience to use a typical drawback (high thermal expansion) as a significant advantage – improved compaction and hassle-free mandrel extraction
- Cut tooling lead time from months to under 10 days
Composite Tooling Success Story

Addressed a rapid-response, critical customer need for a 9-foot-long composite “belly pod” fairing tool

- Multi-segment tool (seven unique sections)
- Produced in < 2 weeks
- Used sparse filled sections and hollow sections with foam fill
- Tool segments joined with printed mechanical joints
- Geometry produces a trapped tool – design of tool segments allowed for “drop out” (easily removable) reusable tooling
- Low temperature cure (200°F), no manual post-processing, quickly sealed with Teflon tape to meet tight time requirements
- Featured in June 2015 Composites World magazine article
Customer Success Story – Large Structures

Boeing FDM C-channel Mandrel, SAMPE 2012
Customer Success Story – Sacrificial Tooling

Enabling an advanced product development team through complex part fabrication

- Aero inlet duct with a complex, trapped-tool geometry
- Wash-out tooling material (ST-130) used in place of multi-piece bonded assembly and traditional wash-out tooling materials
- From concept design to composite part in < 1 week
  - FDM build time is < 24 hours
  - Default porous triangle fill pattern – optimized for autoclave curing and tool dissolution
  - Low temperature (<200°F), 90 psi cure cycle
High Temp Sacrificial Tooling Demonstrator

Northrop Grumman inlet duct demonstrator as part of Air Force Research Lab (AFRL) ManTech Program

- Tool printed in ULTEM S1 break-away support material
- 355°F OoA composite (carbon/epoxy) material system
- Cured at 265°F initially / plus 355°F free-standing post-cure
- Tool removed after post-cure

- Tool build time < 8 days
- Reduced lead time to < 2 weeks
- Tool maintained better than ± 0.040 inch accuracy
Economic Advantages
Examples – Disruptive Cost Reduction

“Small” Tool Example (~6-ft long):

Existing FRP Tooling
Cost – $40-60K (master & mold)
Lead time – 10-14 weeks

FDM Tooling
Cost – $2500
Build time – 40 hours

> 90% cost/time reduction

“Large” Tool Example (~15-ft long):

Existing FRP Tooling
Cost – $80-120K (master & mold)
Lead time – 15-20 weeks

FDM Tooling
Cost – < $25K
Build time – < 2 weeks

> 75% cost/time reduction
FDM Composite Tooling Summary

• Disruptive cost and time savings
• High-temperature, autoclave cure-compatible solutions
• Robust, user-friendly sacrificial tooling solutions
• Highly effective for ancillary tooling – machining, inspection and bonding fixtures, drill jigs, low-temperature masters, and more

➢ Comprehensive Design Guides are available to ensure success
More Information and Resources

www.stratasys.com/webinar-compositetooling

• View webinar on-demand
• Download webinar slides
• Download application documents
• Contact us

Tim Schniepp
Business Development Director – Composite Tooling
Vertical Solutions
Eden Prairie, MN
Timothy.schniepp@stratasys.com
Questions?
THANK YOU